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Estimating a protection factor from homemade facemasks for Los Alamos radioactive aerosols

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Estimating a protection factor from homemade facemasks for Los Alamos radioactive aerosols
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Summary of results. The Los Alamos National Laboratory has required usage of facemasks "whenever interacting with or near others" (LANL 2020). The present document estimates the respiratory protection factor of homemade facemasks to be 1.4 and 1.2 for aerosol particles, below and above 0.3 µm diameter, respectively. This includes an estimated leakage of 70% and 52% for aerosol particles below and above 0.3 µm diameter, respectively.

Table 1. Comparison of expected face coverings, based on studies in relevant literature.

Protection factor for different coverings	Dp < 0.3 um	Dp > 0.3 um	
Homemade facemasks	1.4 ± 1.1	1.2 ± 1.1	Davies et al (2013) and Konda et al (2020)
Mannequin tested commercial facemasks	1.5 ± 1.3	2.4 ± 1.3	Shakya et al (2017)
Mannequin tested respirators.	3.2 ± 1.2	4.9 ± 1.3	Shakya et al (2017)

Introduction

In a recent (Costigan 2020) communication, factors affecting the facemask performance were mentioned:

- Net filtration efficiency of the face covering (homemade or commercial),
- Material (if known, and how many layers, if known),
- Fit of the face covering (intentionally tight, or comfortably loose)
- Moisture on mask at time of release
- Resuspension of material on outside of mask due to exhalation
- Resuspension of material on inside of mask due to exhalation
- Resuspension from mask by touching or removing
- Contact of mask with contaminated surfaces by touching

This document includes an estimate for facemask protection based on the first three factors, and additional information and future work would be required to address the last five factors.

Background

With air filters, for upstream aerosol concentration (C_U) and downstream aerosol concentration (C_D), the ratio of aerosol penetration (P) through filtration material is

$$P = C_D/C_U. \quad (1)$$

The collection efficiency (E) is therefore

$$E = 1 - P, \text{ and of course, } P = 1 - E. \quad (2)$$

Table 2. Examples of the relation between efficiency, penetration and protection factor. (US Navy 2013)

Efficiency Percent	Efficiency ratio, E	Penetration = 1 - E	Protection Factor
80	0.80	0.20	5
90	0.90	0.10	10
95	0.95	0.05	20
99	0.99	0.01	100

Filtration efficiency, material and fit of the face covering

This document used published results from three sources: Public Health England (Davies et al 2013), University of Massachusetts, Amherst (Shakya et al 2017), and Argonne National Laboratory (Konda et al 2020). All three studies measured the aerosol collection efficiency of facemasks and surgical masks, and only Davies et al (2013) did not evaluate respirators (i.e. N95 compliant devices, NIOSH 2019).

Davies et al (2013) used two particles, Bacteriophage MS2, about 0.02 µm diameter and *B. atrophaeus*, about 1 µm diameter (Figure 1). Shakya et al (2017) utilized two aerosol types, monodisperse PSL (polystyrene latex) beads and polydisperse diesel exhaust. The current study reports their 0.1 µm and 2.5 µm PSL results, and their 0.1 µm and 0.5 µm diesel exhaust data (Figure 2). Konda et al (2020) generated NaCl sodium chloride aerosol between a few nanometers and 10-µm diameter, and used two different TSI Inc particle spectrometers to count the aerosol in two size ranges, below and above 0.3 µm diameter (Figure 3). For the three referenced studies, there was no common set of tested aerosol sizes. The current document therefore uses the 0.3 µm size diameter as a dividing line between micron and submicron sizes. This range has been referred to as the "Greenfield gap" (Huang 2017 and Greenfield 1957), and is the boundary between particle sizes dominated by diffusion force effects (below 0.3 µm) and inertial effects (above 0.3 µm). This differentiation in particle size is also consistent with measured particle size distribution in the LANL workplace (Elder et al 1974), where a "fabricating facility" had about 22% activity in the larger-than-micron aerosol size range, while a "chemical recovery facility" had about 74% activity in the submicron aerosol range (Figure 4).

With regard to tested flowrates and filter face velocities, ongoing work at Los Alamos National Laboratory has been evaluating homemade facemasks at the NIOSH (2019) specified flowrate of 85 LPM. The NIOSH (2019) reference does not define an appropriate filter face velocity, but a rectangular facemask with nominal dimensions (12.7 cm x 17.8 cm) experiencing an 85 LPM test flowrate would have an air face velocity of 0.063 m/s. For the referenced articles, the tested face velocities were 0.1 m/s and 0.014 m/s, for Konda et al (2020) and Shakya et al (2017), respectively. The tested face velocity was indeterminate for the Davies et al (2013) work, which used an experimental system described by Wilkes et al (2000). The Wilkes et al (2000) test protocol did not provide definitions for tested filter face velocities, as discussed by Wilkes (2004). Having said that, the information in the Davies et al (2013) approach merited inclusion in this evaluation.

Method

In this study, the aerosol collection efficiencies for 17 different fabric swatches from Davies et al (2013) and Konda et al (2020) were averaged (Figure 6). This represented all of the "homemade" material types tested by the two research groups (Appendix Calc 1). Konda et al (2020) also measured the effect of a leak (i.e. a poor fit for a face covering) on three different systems: an N95 respirator, a surgical mask, and their best homemade facemask material (a cotton/silk hybrid layer construction). The comparison between these tests, with and without the gapped leak, was used to calculate a leak effect ratio, which was applied to the results of the homemade facemask materials that were tested without a designed leak. This set of estimated values represented a possible lower bound for homemade facemasks. Shakya et al (2017) measured aerosol collection efficiency (Figure 2) for commercially available masks and respirators (Figure 5), and their results represent an upper bound for homemade respirator performance.

Results and Discussion

The results (Table 3) aggregate the information from the three referenced research groups. For homemade facemasks, in this particular approach, the protection factors of 1.4 and 1.2 reflect the net collection efficiencies of 29.0% and 19.3%, for the smaller and larger size ranges, respectively.

For the tested commercial masks and respirators, the protection factor for aerosol larger than 0.3 µm is larger than for the aerosol smaller than 0.3 µm.

Table 3. Extended results summary

DATA SUMMARY	Dp < 0.3 um	Dp > 0.3 um	Davies et al (2013) and Konda et al (2020)
Homemade facemask material efficiency	61.08	65.26	= Eff
Leak effect ratio	0.475	0.295	= Leak ratio
Efficiency net with leak estimate	29.0	19.3	=Eff net
Protection factor	1.4 ± 1.1	1.2 ± 1.1	=1/(1-Eff net/100)
	Dp < 0.3 um	**Dp > 0.3 um**	**Shakya et al (2017)**
Efficiency net with mannequin leak	33.67	58.00	=Eff net
Protection factor for commercial masks	1.5 ± 1.3	2.4 ± 1.3	=1/(1-Eff net/100)
	Dp < 0.3 um	**Dp > 0.3 um**	**Shakya et al (2017)**
Efficiency net with mannequin leak	68.67	79.50	=Eff net
Protection factor for N95 type respirator	3.2 ± 1.2	4.9 ± 1.3	=1/(1-Eff net/100)

Considerations for future work

Factors of moisture, resuspension and physical transfer were not included in the estimate in this current document, but relevant literature are mentioned here as reference materials for further work.

The behavioral characteristics of Pu-238 material in fabrication processes and filtration activities were described by Duncan and McKane (2009). Congdon (1996) interpreted Pu-238 powder as having more of a gaseous phenomenon with neutrally buoyant or even thermal plume characteristics, where material transport over distances of hundreds of feet were common. He also mentioned that the adhesion of Pu-238 particles is diminished due to self-heating, which diminishes water moisture retention in Pu-238 material. Icenhour (2005) provided a review of past work describing alpha recoil effects on powder and aerosol particles. He notes a release rate by fragmentation of Pu-238 material into particles of about 0.3 µm was estimated (Biermann et al 1991) to be about 5% by weight per month.

McDonagh and Byrne (2014) found that increased physical activity (by a human test subject) and fabric type had large influences on resuspension of 3 µm, 5 µm and 10 µm diameter silica test aerosol. Notably, fleece fabric exhibited about twice the resuspension of polyester, denim or cotton, on a relative basis.

Licina and Nazaroff (2018) found in between 0.3% to 3% of deposited aerosol was resuspended from fabric made of a 35% to 65% cotton polyester blend (to mimic hospital scrubs). The resuspended aerosol concentrations peaked within the first 5 minutes of experimental resuspension activities performed by a programmable anthropomorphic robot.

The influence of fabric type was also investigated by Bohne and Cohen (1985), where they measured less resuspension from Nomex™ fabrics than from cotton fabric.

Basic technical introductions and review articles on particle resuspension and reentrainment can be found in Corn (1961 No. I), Corn (1961 No. II), Corn and Stein (1965), Sehmel (1980) and John (1995).

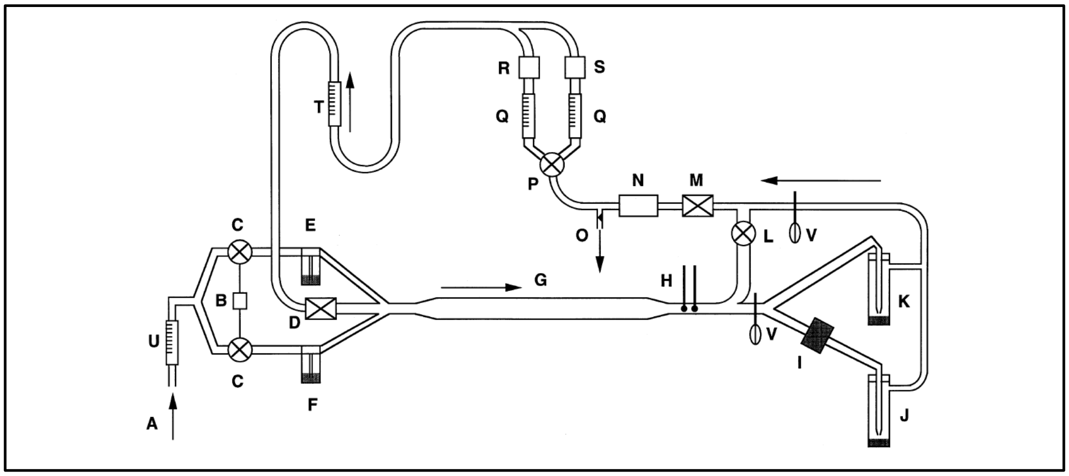

Figure 1. Davies et al (2013) tested fabric swatches with bioaerosols of about 0.02 and 1 μm diameter.

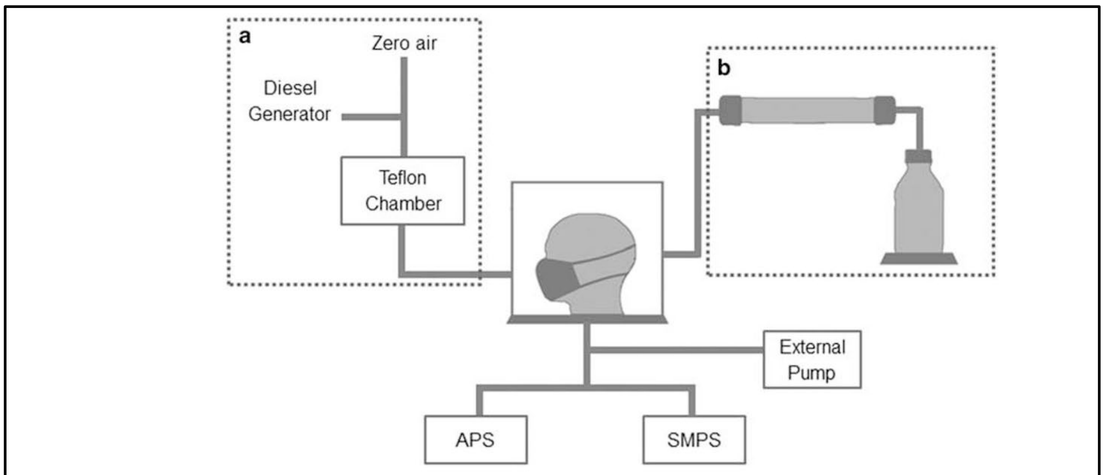

Figure 1. Experimental setup of (a) diesel generated particles and (b) atomizer to generate polystyrene latex (PSL) particles.

Figure 2. Shakya et al (2017) used a mannequin head with facemasks to measure fit test information.

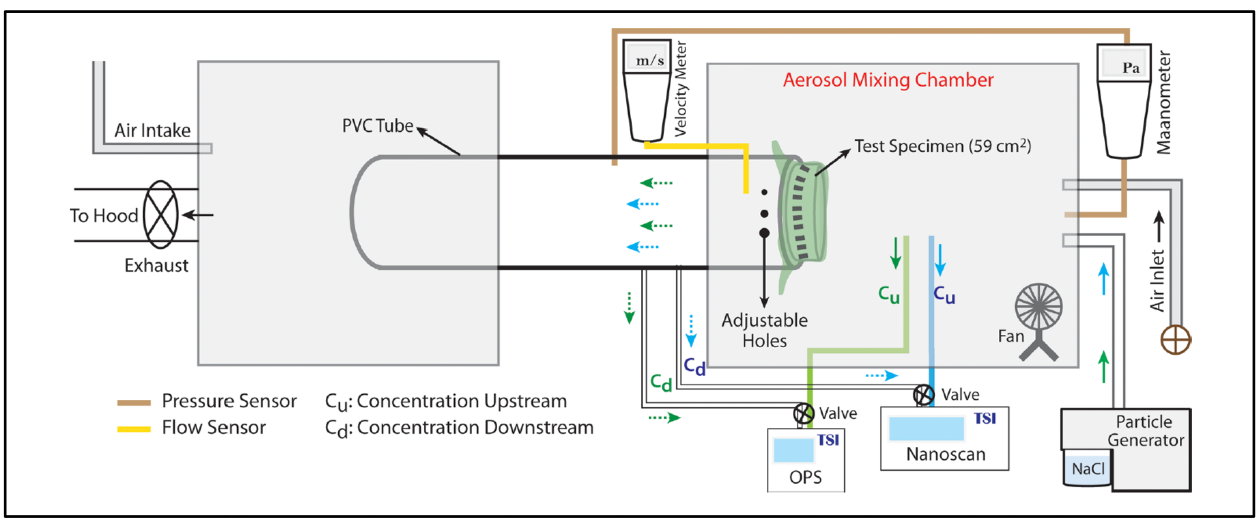

Figure 3. Konda et al (2020) measured aerosol collection efficiency with an engineered leak (adjustable holes).

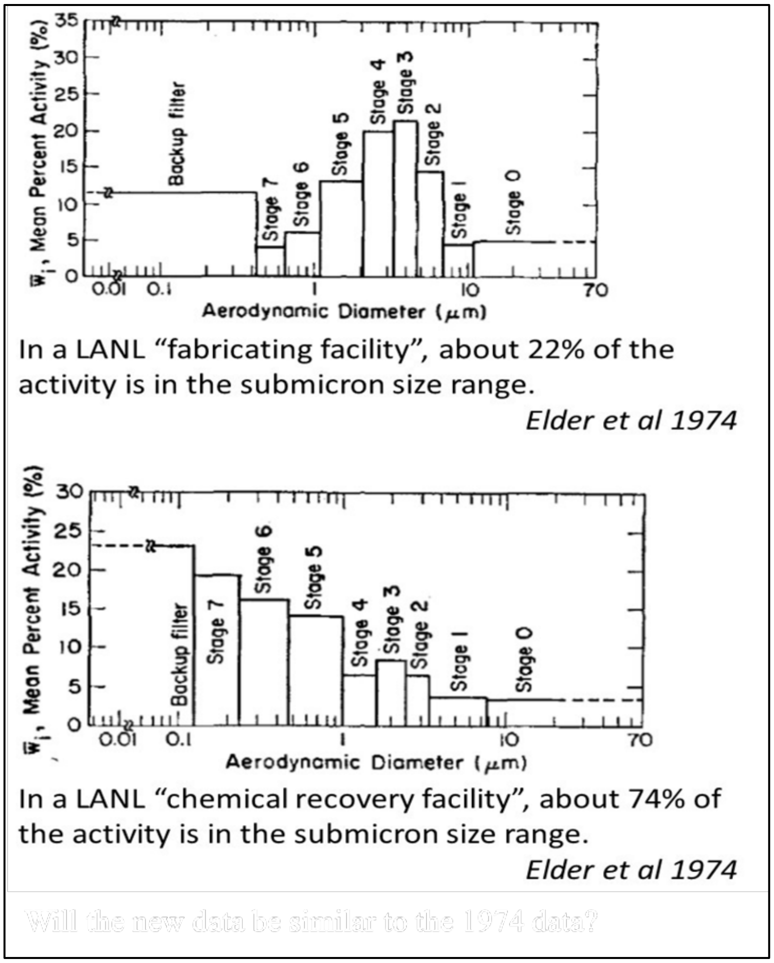

Figure 4. Summary of graphical data from Elder et al 1974 (as referenced by Berg and Moore 2016).

Figure 5. Masks (for air pollution mitigation in Asian markets) and N95 respirators. (Shakya et al 2017)

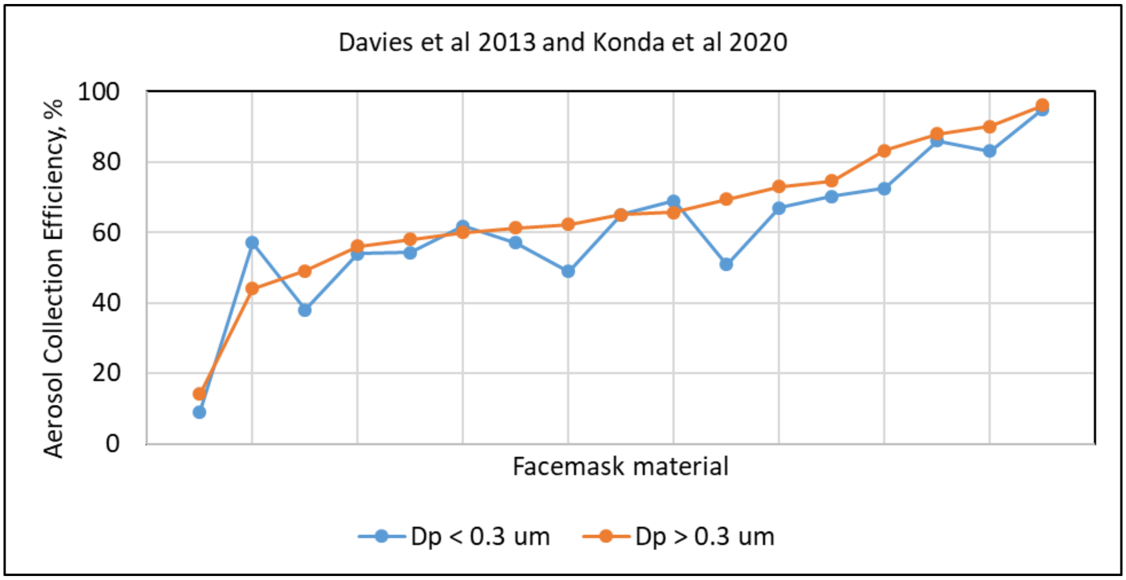

Figure 6. Efficiency tests of fabric swatches. To minimize bias, only one sample above 90% measured efficiency from Konda et al (2020) was included. This set of results indicates a wide range of possible collection efficiencies in homemade mask materials.

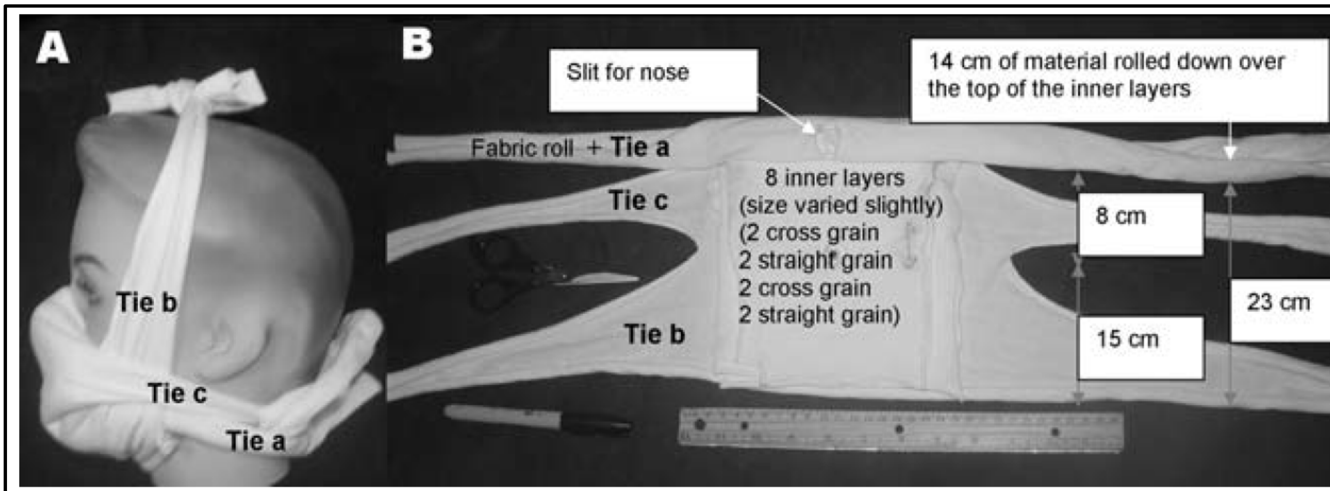

Figure. Prototype mask: A) Side view, B) Face side. This mask consisted of 1 outer layer (≈37cm × 72 cm) rolled and cut as in panel B with 8 inner layers (≤18 cm^2) placed inside (against the face). The nose slit was first placed over the bridge of the nose, and the roll was tied below the back of the neck. The area around the nose was adjusted to eliminate any leakage. If the seal was not tight, it was adjusted by adding extra material under the roll between the cheek and nose and/or pushing the rolled fabric above or below the cheekbone. Tie b was tied over the head. A cloth extension was added if tie b was too short. Finally tie c was tied behind the head. The mask was then fit tested.

Figure 7. Dato et al (2006) designed a homemade mask with a reported protection factor of 67. They provide this disclaimer in their article, “When made by naive users, this mask may be less effective because of variations in material, assembly, facial structure, cultural practices, and handling. No easy, definitive, and affordable test can demonstrate effectiveness before each use. Wearers may find the mask uncomfortable.”

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